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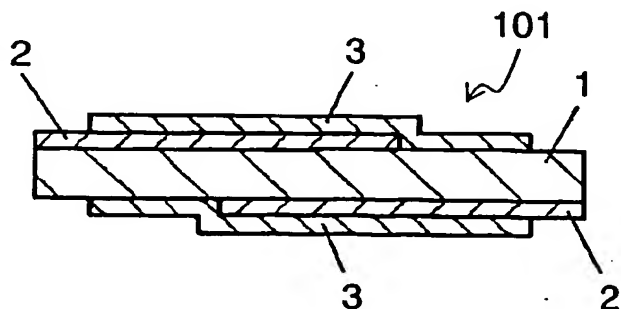
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(54) Title: PIEZOELECTRIC VIBRATOR, FILTER USING SAME, AND METHOD FOR ADJUSTING PIEZOELECTRIC VIBRATOR

(54) 発明の名称: 圧電振動子、それを用いたフィルタ及び圧電振動子の調整方法



(57) Abstract: A piezoelectric vibrator is characterized by having a multilayer structure wherein both major surfaces of a piezoelectric plate (1) are respectively provided with a silicon oxide film (3) having a generally equal thickness as a dielectric film. By having such a structure, namely by having the dielectric films on both major surfaces of the piezoelectric plate (1), the difference in the internal stresses, which are caused by the difference in long-term stress relaxation and act on the piezoelectric plate (1) and the dielectric films, is made smaller, thereby greatly suppressing warp of the piezoelectric vibrator. Consequently, a change of the resonance frequency of the piezoelectric vibrator due to warping of the piezoelectric vibrator can be made smaller.

(57) 要約: 本発明の圧電振動子は、圧電板 (1) の両主面にほぼ同じ厚みの酸化珪素膜 (3) を誘電体膜として設けた積層構造であることを特徴とする。上記構造をとることで、誘電体膜が圧電板 (1) の両主面に存在するため長期的な応力緩和の差に起因する圧電板 (1) や誘電体膜に働く内部応力の差が小さくなり、反りを極力小さくすることができる。よって、圧電振動子が反ることによる圧電振動子の共振周波数の変化を小さくすることができるという効果を有する。

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## DESCRIPTION

### PIEZOELECTRIC VIBRATOR, FILTER USING THE SAME AND ITS ADJUSTING METHOD

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#### TECHNICAL FIELD

The present invention relates to a piezoelectric vibrator, a filter using the same and its adjusting method.

#### 10 BACKGROUND ART

As a piezoelectric element using a bulk wave which travels through a solid, a piezoelectric vibrator used as a source of clock signals for various electronic instruments or a piezoelectric filter used for sampling frequencies of communication instruments is known. Recently, the piezoelectric element has  
15 been used at a high frequency. Most of the piezoelectric elements employ thickness shear vibration or thickness longitudinal vibration as principal vibration, and a resonance frequency of the principal vibration is inversely proportional to a thickness of a piezoelectric plate. Therefore, the piezoelectric element is attempted to be used at a higher frequency by forming the  
20 piezoelectric plate with a thin film or the like.

The conventional piezoelectric element is disclosed in "Properties of Aluminum nitride thin films for piezoelectric transducers and microwave filter applications", written by Marc-Alexander Dubois and Paul Murant, on pp. 3032-3034 of Applied Physics Letters in May 17, 1999.

25 As shown in conventional piezoelectric element 901 of Fig. 9, aluminum nitride thin film 91 is used as the piezoelectric plate, and exciting electrodes 92 are formed on its front and back. A dielectric film formed of a laminated layer

of silicon nitride film 93 and silicon oxide film 94 is disposed at one surface of film 91. In addition, the whole piezoelectric vibrator is disposed on silicone substrate 95 so that very thin piezoelectric vibrator is treated easily.

In the conventional structure discussed above, an elastic constant of the piezoelectric film and the dielectric film and a size thereof are determined in a manner that a temperature coefficient of the resonance frequency of the piezoelectric vibrator becomes zero at an initial stage after deposition. However, in the conventional structure, long-term reliability for stress relaxation of each film is not considered. Therefore, according as time passes, a warp, namely a change in size, of the whole piezoelectric vibrator becomes larger than that at the initial stage because of a difference of the stress relaxation of the piezoelectric film and the dielectric film. As a result, this warp brings a change in resonance frequency.

## 15 SUMMARY OF THE INVENTION

The present invention is directed to solve the problems discussed above and therefore, it is an object of the invention to provide a piezoelectric vibrator whose change in a resonance frequency caused by a warp is small, a filter using the vibrator and an adjusting method thereof.

20 According to the present invention, in the piezoelectric vibrator where polarization of a piezoelectric plate points in a direction of a thickness, electrodes are formed at both faces of the piezoelectric plate. Furthermore, dielectric films are formed at the both faces of the piezoelectric plate. In addition, these dielectric films are substantially symmetric with respect to a point across the piezoelectric plate and geometrically similar, and substantially  
25 have the same thickness. The piezoelectric plate employs thickness longitudinal vibration as principal vibration.

Using the structure discussed above, because dielectric films are formed at the both faces of the piezoelectric plate, a difference of internal stress, which is caused by a difference of stress relaxation in a long term and affects the piezoelectric plate or the dielectric film, becomes small. Therefore, the warp  
5 can be considerably small. As a result, a change, which is caused by the warp of the piezoelectric vibrator, in a resonance frequency of the piezoelectric vibrator can be small.

#### BRIEF DESCRIPTION OF THE DRAWINGS

10 Fig. 1 is a sectional view of a piezoelectric vibrator in accordance with an exemplary embodiment of the present invention.

Fig. 2 shows a relation between a ratio of a thickness of a dielectric film to that of a piezoelectric plate and an electromechanical coupling factor.

15 Fig. 3 is a sectional view of a piezoelectric vibrator in accordance with another exemplary embodiment of the present invention.

Fig. 4 shows an electrical equivalent circuit of a ladder type filter using the piezoelectric vibrator.

Fig. 5 is a perspective view of the ladder type filter in accordance with an exemplary embodiment of the present invention.

20 Fig. 6 is a sectional view of a double mode piezoelectric filter.

Fig. 7 is a sectional view of a double mode piezoelectric filter.

Fig. 8 is a sectional view of a double mode piezoelectric filter in accordance with an exemplary embodiment of the present invention.

25 Fig. 9 is a sectional view of a conventional piezoelectric vibrator.

#### DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Exemplary embodiments are demonstrated hereinafter with reference to

Fig 1 through Fig 8.

### FIRST EXEMPLARY EMBODIMENT

Fig. 1 is a sectional view showing piezoelectric vibrator 101 which uses  
5 aluminum nitride as its piezoelectric material and a fundamental mode of  
thickness longitudinal vibration as principal vibration. Polarization thereof  
points in a direction of a thickness of a piezoelectric plate. Piezoelectric  
vibrator 101 is formed of piezoelectric plate 1 made of aluminum nitride,  
exciting electrodes 2, facing each other, provided at both faces of piezoelectric  
10 plate 1 and silicon oxide films 3 disposed on both faces of piezoelectric plate 1 as  
dielectric films.

Piezoelectric plate 1 made of aluminum nitride has a thickness of 1  $\mu\text{m}$ .  
Silicon oxide films 3 are formed at both faces of piezoelectric plate 1 so as to  
have the same thickness of 0.4  $\mu\text{m}$  and substantially the same area each other.  
15 Therefore, a difference of internal stress, which is caused by a difference of  
stress relaxation in a long term and affects piezoelectric plate 1 or the silicon  
oxide, becomes small. Accordingly, a warp can be considerably small. As a  
result, a change, which is caused by the warp of the piezoelectric vibrator, in a  
resonance frequency of piezoelectric vibrator 101 can be small.

20 The silicon oxide used as material of silicon oxide film 3 has a negative  
temperature coefficient of frequency. On the other hand, aluminum nitride  
used as material of piezoelectric plate 1 has a positive temperature coefficient of  
frequency. By laminating these materials, i.e., silicon oxide and aluminum  
nitride, the temperature coefficient of frequency can be substantially canceled,  
25 so that the temperature characteristics of frequency can be improved. The  
same effect can be obtained by using a laminated layer formed of a silicon oxide  
film and a silicon nitride film instead of the silicon oxide film as material of

silicon oxide film 3.

According to the first embodiment, a fundamental mode is used as principal vibration. Therefore, variations in the resonance frequency for variations in thickness of piezoelectric plate 1 or silicon oxide film 3, i.e., dielectric film, are reduced approximately half compared with a 2nd overtone mode. As a result, the resonance frequency or an electromechanical coupling factor can be precisely adjusted to a desired value.

The resonance frequency of piezoelectric vibrator 101 is determined by a thickness of piezoelectric plate 1, a thickness of exciting electrode 2 and a thickness of silicon oxide film 3. In addition, the electromechanical coupling factor, which is one of important items of electrical characteristics, is known to be also changed by thicknesses thereof.

Fig. 2 shows variations in the electromechanical coupling factor of piezoelectric vibrator 101 which uses aluminum nitride as its piezoelectric material and in which polarization of piezoelectric plate 1 points in a direction of a thickness of piezoelectric plate 1. Piezoelectric vibrator 101 forms silicon oxide films 3 having the same thickness on both faces of piezoelectric plate 1 as dielectric films. In particular, Fig. 2 shows variations in the electromechanical coupling factor in a case where ratio " $t_s/t_p$ " indicating the ratio of sum " $t_s$ " to thickness " $t_p$ " is changed. Sum " $t_s$ " indicates the sum of a thickness of silicon oxide film 3 of one side of piezoelectric plate 1 and a thickness of another silicon oxide film 3 of the other side of piezoelectric plate 1. Thickness " $t_p$ " indicates a thickness of piezoelectric plate 1. Fig. 2 shows the electromechanical coupling factors in cases of the fundamental mode of the thickness longitudinal vibration and the 2nd overtone mode thereof.

As shown in a result of a simulation of Fig. 2, in both cases of the fundamental mode and the 2nd overtone mode, when ratio " $t_s/t_p$ " ranges not

less than 0.7 and not more than 2.0, variations in the electromechanical coupling factors range within 0.25% of a minimum value thereof. In other words, the coupling factors of the fundamental mode are stabilized within 9.5-11.5 %, and the coupling factors of the 2nd overtone mode are also stabilized within 12.0-14.0 %. Because the electromechanical coupling factors become

5 stable, stable characteristics can be obtained in cases where a piezoelectric vibrator is used in a voltage-controlled oscillator (VOC), a piezoelectric filter is formed of a plurality of piezoelectric vibrators or the like.

When ratio "ts/tp" becomes larger than 2.0, a mass load for the thickness

10 longitudinal vibration becomes too much and a mechanical quality factor, which is an index of easiness of vibration, becomes small, so that it is not suitable for practical use.

In an adjusting process where the resonance frequency of the piezoelectric vibrator is adjusted to the desired value, a silicon oxide film is

15 further disposed on or removed from one of the silicon oxide films formed on aluminum nitride so that silicon oxide film 3 having a certain thickness is formed.

According to the first embodiment, sum "ts" of a thickness of silicon oxide film 3 of one side of piezoelectric plate 1 and a thickness of another silicon oxide

20 film 3 of the other side of piezoelectric plate 1 is 0.8  $\mu\text{m}$ . Thickness "tp" of piezoelectric plate 1 made of aluminum nitride is 1 $\mu\text{m}$ . Therefore, ratio "ts/tp" becomes 0.8. Because ratio "ts/tp" ranges not less than 0.7 and not more than 2.0, namely, within an area where variations in the electromechanical coupling factor become small, the electromechanical coupling factor is hardly changed at

25 the adjustment of the resonance frequency. In a word, according to the first embodiment, the adjusting process where the electromechanical coupling factor is hardly changed can be realized.

In the first embodiment, aluminum nitride is used as piezoelectric material, however, the same effect can be obtained by using other piezoelectric material such as PZT or ZnO.

Furthermore, in this embodiment, the method of adjusting resonance frequencies is described by further disposing or removing a silicon oxide film on one of the silicon oxide films formed on piezoelectric vibrator 101. However, in order to adjusting resonance frequencies, a silicon oxide film may be disposed on or removed from the other of the silicon oxide films. In addition, silicon oxide films may be disposed on or removed from both of the silicon oxide films.

## SECOND EXEMPLARY EMBODIMENT

Fig. 3 is a sectional view showing piezoelectric vibrator 301 which uses aluminum nitride as its piezoelectric material and a 2nd overtone mode of thickness longitudinal vibration as principal vibration. Polarization thereof points in a direction of a thickness of a piezoelectric plate. Piezoelectric vibrator 301 is formed of piezoelectric plate 1 made of aluminum nitride, exciting electrodes 2, facing each other, provided at both faces of piezoelectric plate 1, silicon oxide film 3, which is used as a first dielectric film, disposed on a back face of piezoelectric plate 1 and silicon nitride film 4, which is used as a second dielectric film, disposed on a front face of piezoelectric plate 1. Supporting substrate 5 supports piezoelectric vibrator 301.

Piezoelectric plate 1 made of aluminum nitride has a thickness of 10  $\mu\text{m}$ . Silicon oxide film 3 has a thickness of 4  $\mu\text{m}$ , and silicon nitride film 4 has a thickness of 5  $\mu\text{m}$ , so that dielectric films having substantially the same thickness each other are formed at both sides of piezoelectric plate 1.

In addition, an area of silicon nitride film 4 is formed so as to be substantially the same as an area of silicon oxide film 3. In other words, the



area of silicon nitride film 4 becomes 0.8-1.2 times as large as that of silicon oxide film 3. Therefore, a difference of internal stress, which is caused by a difference of stress relaxation in a long term and affects piezoelectric plate 1 or the dielectric film, becomes small. Accordingly, a warp can be considerably  
5 small. As a result, a change, which is caused by the warp of piezoelectric vibrator 301, in a resonance frequency of the piezoelectric vibrator can be small.

In the second embodiment, the piezoelectric vibrator may be produced according to the following processes.

Disposing silicon nitride film 4 on supporting substrate 5 made of silicon  
10 by injecting nitrogen,

Forming piezoelectric vibrator 301, which uses aluminum nitride as its piezoelectric material, thereon, and

Removing supporting substrate 5 from its back by chemical etching or the like to make a vibration section of piezoelectric vibrator 301 a hollow  
15 structure.

Using the processes discussed above, piezoelectric vibrator 301 can be produced easily because silicon nitride film 4 can work for stopping the etching of supporting substrate 5.

In addition, according to the present embodiment, approximately two  
20 times higher resonance frequency can be obtained compared with a fundamental mode by using a 2nd overtone mode as principal vibration.

As discussed above, in a case where a high resonance frequency is required, a 2nd overtone mode is selected. In a case where easy adjustment of a resonance frequency takes priority, a fundamental mode is selected.

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### THIRD EXEMPLARY EMBODIMENT

A band-pass filter, which can pass signals in specific frequencies, is

known to be produced by combining a plurality of piezoelectric vibrators. In general, a ladder type filter, which uses a resonance frequency or an anti-resonance frequency of a vibrator as a pole of a filter characteristic and uses an interval between the resonance frequency and the anti-resonance frequency as a pass band, is provided. Fig. 4 shows an electrical equivalent circuit of the ladder type filter using two piezoelectric vibrator 11.

Fig. 5 shows ladder type filter 501 which is formed by a connection shown in the electrical equivalent circuit of Fig. 4. Ladder type filter 501 uses two piezoelectric vibrator 11 which uses aluminum nitride as its piezoelectric material and a fundamental mode of thickness longitudinal vibration as principal vibration. Polarization thereof points in a direction of a thickness of a piezoelectric plate. Ladder type filter 51 is formed of piezoelectric vibrator 11, external terminal 12 for inputting, external terminal 13 for outputting, external terminal 14 for grounding and bonding wire 15. Each of two piezoelectric vibrator 11, which are used in ladder type filters 51, has a laminated structure where dielectric films having substantially the same thickness are disposed at both faces of a piezoelectric plate. Therefore, because the resonance frequency or an electromechanical coupling factor of the piezoelectric vibrator is stable, filter characteristics having a stable band width or the like can be obtained.

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#### FOURTH EXEMPLARY EMBODIMENT

A multiple mode filter, which forms a band-pass filter by arranging a plurality of piezoelectric vibrators at one piezoelectric plate and combining vibrations thereof, is used as a filter except a ladder type filter. These filters are also called Monolithic Crystal Filter (MCF) which positively use vibration called inharmonic overtone such as  $a_0$  mode or  $s_1$  mode. A double mode filter using two modes, i.e.,  $s_0$  mode and  $a_0$  mode is described hereinafter.

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One example of a structure of double mode filter 601 is shown in Fig. 6. Electrode 21 for inputting and electrode 22 for outputting are formed at a small interval on one face of piezoelectric plate 1, and electrode 23 for grounding is formed on the other face thereof. Using the structure mentioned above, the band-pass filter is provided by generating s<sub>0</sub> mode of a symmetric mode and a<sub>0</sub> mode of an asymmetric mode. Fig. 6 shows an example that only one electrode 23 for grounding is formed. However, as shown in Fig. 7, electrode 231 for grounding corresponding to electrode 21 for inputting and electrode 232 for grounding corresponding to electrode 22 for outputting may be formed.

Fig. 8 shows double-mode piezoelectric filter 801, which uses aluminum nitride as its piezoelectric material and a fundamental mode of thickness longitudinal vibration as principal vibration, of the present invention. Piezoelectric filter 801 is formed of piezoelectric plate 1 made of aluminum nitride, electrode 21 for inputting, electrode 22 for outputting, electrode 23 for grounding, silicon nitride film 24 disposed on a back face of piezoelectric plate 1 and silicon oxide film 25 disposed on a front face of piezoelectric plate 1. Supporting substrate 26 made of silicon supports piezoelectric filter 801. Piezoelectric filter 801 has a laminated structure where dielectric films (i.e., silicon nitride film 24 and silicon oxide film 25) having substantially the same thickness and area are disposed at both faces of piezoelectric plate 1. Therefore, because the resonance frequencies of the two vibration modes are stable, filter characteristics having a stable band width or the like can be obtained.

## 25 INDUSTRIAL APPLICABILITY

As discussed above, according to the present invention, in a piezoelectric vibrator where polarization of a piezoelectric plate points in a direction of a

thickness, exciting electrodes are formed at both faces of the piezoelectric plate. Furthermore, dielectric films are formed at the both faces of the piezoelectric plate. In addition, these dielectric films are substantially symmetric with respect to a point across the piezoelectric plate and geometrically similar, and substantially have the same thickness. The piezoelectric plate employs thickness longitudinal vibration as principal vibration. Using the structure discussed above, a difference of internal stress, which is caused by a difference of stress relaxation in a long term and affects the piezoelectric plate or the dielectric film, becomes small. Therefore, a warp can be considerably small.

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10 As a result, a change, which is caused by the warp of the piezoelectric vibrator, in a resonance frequency of the piezoelectric vibrator can be small.